MEMORANDUM ON WAR PRODUCTION PROBLEMS

Presented to the Production Council of the Cabinet by the War Emergency Committee of the Institution.

THE INSTITUTION OF PRODUCTION ENGINEERS,
36, Portman Square,
LONDON, W.1.

2nd September, 1940

To the RIGHT HON. ARTHUR GREENWOOD, P.C., M.P.,
Chairman of the Production Council,
Treasury Chambers, Whitehall, S.W.1.

SIR,—The Institution of Production Engineers constituted a War Emergency Committee from its members two months ago for the purpose of ascertaining in what way the Institution might best assist war production.

In the course of its many deliberations and studies the War Emergency Committee has investigated problems and difficulties involved in the production of war material over a wide range of products and circumstances.

It has been the guiding principle of the War Emergency Committee that it should present for the solution of problems submitted to it only practical, constructive suggestions and it has endeavoured to do its work in this way. As a result of the mass of material which has been considered, the War Emergency Committee has come to some very definite conclusions which it feels strong y must be of interest to yourself and which it therefore feels its duty now to place before you. It may seem that the points discussed are elementary in some cases but they are brought forward because we have ample evidence that they are not as fundamentally appreciated throughout Administrative Departments as they should be.

We do not claim that this memorandum is exhaustive, but we do state it as our opinion that it includes the most urgent points for consideration at the present time.

(*Vol. XIX, No. 10, October, 1940*)

Our recommendations are as follows :—

THAT THE FOLLOWING THREE SPECIFIC SUGGESTIONS SHOULD BE ADOPTED FOR THE FURTHER IMPROVEMENT OF DESIGNS WITH THE OBJECT OF FACILITATING PRODUCTION.

(*a*) That the many "concessions" which have been granted to individual manufacturers but which have not been so far reflected in changes to drawings should now be consolidated by entry into the permanent design records so as to make them available for all manufacturers.

(*b*) That emphasis should be placed upon the great quantity of unused press capacity in the country and that designs should be influenced in the direction of using press rather than turning capacity.

(*c*) That use should be made of the voluntary services of a panel of experts from the Institution of Production Engineers in order to review their projects with the design personnel of the Ministeries, thus providing them at the inception of designs with advice, so that mechanical details might be shaped to facilitate cheap and quick production.

(*a*) Much excellent work has been done as a result of the Government drive for designs to be modified where production would be facilitated by so doing and many of the design staffs and other officials concerned have adopted a very helpful attitude in relation to this point. It is common to find that one of a group of manufacturers producing an article will be more progressive than the others and will suggest a number of improvements or simplifications which will be approved. It is, as a rule, the practice of Ministeries not to have the resulting changes made in the permanent design records and drawings but to give the firm concerned a written "concession" for a certain number of the articles to be delivered in accordance with the proposed change. Since the war has started, however, and to some extent even earlier, there have accumulated a great number of such concessions but they are often known only to the firm from which they originated. In many instances, therefore, the need to-day is not so much for a redesign from first principles as for a consolidation of the mine of valuable improvements contained in the concessions which have accumulated. If this information were passed on to all manufacturers of the article concerned a notable reduction in cost and increase in output would be obtainable.

(*b*) In industry it often happens that a newly developed mechanism in its early stages is designed with relatively small quantity production in mind and, later, a stage is reached at which the new development has become stabilised and finds a big market and a complete redesign is undertaken as a prelude to big quantity pro-

duction. At this stage it is common for industry to design in such a way as to make use of pressing, die-casting and moulding as manufacturing processes, since each of these is fundamentally a quicker process than the cutting operations such as turning, milling and drilling. At the same time, press operations commonly involve higher tool costs than turning and milling operations and are consequently not adopted unless the quantity to be produced at a lower labour cost and often at a cheaper raw material cost, is sufficient to offset the higher tool cost.

A wide range of the Stores required for war purposes were originally designed for small quantity production and have not undergone the review which would adapt them for the large quantity production now needed. As a result there is in the country a very large quantity of press capacity unused. The balance of the incidence of pressing and of other forms of production operation is not the same to-day as before the war, largely for the above reason. Consequently, the underload of press work is accompanied by an overload of turning work and a national shortage has developed of such turning machines as Capstan lathes and their equipment. Another undesirable outcome of this same trend is that designs based upon the cutting operations usually consume more raw material than designs based upon the pressing operations. Not only is press capacity available in the country but the heavy load of tool making also has changed in character from the normal balance and it is now far easier to secure press tools than to secure the jigs, fixtures and small tools needed for the cutting operations. The difficulty is further accentuated by the fact that the making of jigs and fixtures itself involves more lathe work than the making of press tools, so that in every direction the country's engineering production capacity has been thrown out of balance to a very important extent.

We have collected many examples demonstrating how parts designed for production on lathes can often be redesigned without effect upon interchangeability so as to be made with press tools and we are of the opinion that conversions of this kind should be widely extended. We are sure that in a few months such a trend would save a great deal of money to the country and secure additional production.

(*c*) The willingness of the Design Departments of the Ministeries to consider any device offered which will result in production being facilitated through the simplification of design is being widely demonstrated and the old difficulties which industry experienced in this direction are rapidly disappearing. It is, therefore, felt that the time is ripe to offer the voluntary services of a panel of expert production engineers who would be available to go over designs with the design staffs of the Ministeries and to advise them

how the details could be best shaped so as to facilitate production. Such a review need have nothing to do with the overall conception of the article but would concern itself with the mass of detail which, as a rule, determines cost and production methods. Such a panel could be made up of experts in different spheres, such as in press work, die casting, moulding, heat treatment, grinding, according to the needs of the design under review. Very little time would have to be spent on each detail to indicate the approach which would free the part from those troubles which entail costly production methods or the unnecessary use of skilled labour. Such a panel could rapidly influence designs towards the press work basis recommended under (*b*) and could bear in mind, either from its own knowledge or as a result of information specially given to it, the types of production plant into which a design should be guided according to the unbalance of plant known to exist around the country.

The Institution has, among its members, a great many men who would be qualified to constitute such an impartial panel. The personnel of the panel could thus be varied in order that the time demanded from any one member should not be excessive. We are confident that these men would be glad to help in such a way and that this proposal would serve to provide the Design Departments with just the very information which they are seeking.

THAT STEPS SHOULD BE TAKEN TO IMPRESS UPON THE PERSONNEL OF CONTRACTS DEPARTMENTS AND PRODUCTION DIRECTORATES CERTAIN OF THE BASIC PRINCIPLES OF PRODUCTION WITH THE OBJECT OF UTILISING THE PRODUCTIVE CAPACITY OF INDUSTRY MORE EFFICIENTLY THAN AT PRESENT; AND THAT WHERE ORDERING IN BIG VOLUME IS CONTEMPLATED, A PARTICULAR SYSTEM OF ORDERING SHOULD BE ADOPTED.

Pre-Production Preparations.

Production may generally be classified under three headings :—

(*a*) Jobbing, which is the production of special very small quantities, such as model making.

(*b*) Batch or Volume production, which is the production of small or large quantities with the aid of tools designed to suit the quantities ordered and subject to repetition on a similar scale of ordering.

(*c*) Continuous Production, which is the "straight line" or flow production carried out with the aid of more elaborate tools, sometimes with special machine tools, and involves the organisation of production in such a way as to aim towards the permanent balance of the plant involved.

Both classes (*b*) and (*c*) must inherently be founded upon some reasonable knowledge of the total duration of the production of the article concerned. Both the rate of flow and duration of the job are essential basic factors on which all planning will be built.

Each of these classes of production will range within its own extremes according to the quantity to be produced and the size and character of the product and the very decision into which class a given product will fall must be based upon a reasonably accurate knowledge of the total volume of requirements. Failure to foresee these requirements is likely to result in inefficiency in planning and later in production because of the wrong choice of the basic class of treatment which the project is to receive.

Tooling for Production.

In view of the wide range of possibilities outlined under the above three classes it must be emphasised that the term " Tooling for Production " does not have any one meaning but indicates a range of possibilities, the choice of which is mainly based upon the required volume, rate of flow and continuity of orders indicated at the time the job is first planned for production.

As a concrete illustration of the misunderstandings which can arise due to lack of appreciation of this point, a case recently occurred in which a certain Production Directorate had instructed two firms to " Tool up " for the same product. The initial orders were for 200 from firm " A " and 1,000 from firm " B." The firm " A " proceeded to tool up for a production of 50 per week as they had been instructed that there was a likelihood of future orders at that rate. The production was planned and tooled for an existing Instrument Shop as the type of product and the output suggested was suitable for that method of production. The firm " B," who received the initial order for 1,000, were in the habit of handling volume production using semi-skilled labour backed by efficient tooling and proceeded to tool up the order in accordance with their normal manufacturing procedure. The increased tool cost incurred by " B " was largely offset by the additional labour cost incurred by " A " owing to the different character of " A's " tooling. The demand for the product ultimately proved to be vastly in excess of the 50 per week on which basis " A " had tooled up but, fortunately for the Production Directorate concerned, the firm " B," owing to the different initial approach to the job and consequent more adequate tooling up, were able to meet the demands. On the other hand, the Production Directorate were very much disturbed to find out that while both firms had been instructed to tool up for the same product, one was unable to produce at a greater rate than the 50 per week while the other firm was able to meet a much larger demand.

In effect, therefore, it is necessary in the initial stages of production to reach an understanding with firms regarding the rate of production and class of method which will be used in order to ensure that the means for production of the product concerned are in line with probable future requirements as regards rate and duration of output. Different approaches to the same job will result in widely differing possibilities for expanding production.

Continuous or Flow Production.

Basically, continuous or flow production involves the settling of plans within a factory which enable the product under consideration to be continuously produced from start to finish and for all operations to flow at an equal rate or to take place at uniform intervals of time. Such preparations and planning are complex and are seriously dislocated if flow is interrupted.

There are in Breat Gritain not a great many factories organised on the basis of complete flow or line production since such organisation requires very heavy and continuous demands which, in this country, seldom arise. It is more common to find a factory organised so that flow characteristics are wherever possible obtained although the products on which the factory is engaged consist actually of large volumes of a variety of articles. The essential point is the necessity, in any large volume production, for the organisation to be built around the basic ideal of production flow. Each of the multitudinous production channels within the factory must be regarded as a pipeline through which production must flow and any temporary stoppage to that flow must involve a reduction in the total output attained which can never be regained. Emphasis must, therefore, be laid upon the fact that time consciousness is one of the basic necessities in successful volume or continuous production. *It is this feature, perhaps beyond all others, which appears to be least appreciated in Production Directorates and which is the greatest cause of loss of output in the supply of Stores to Government Departments.*

In elaboration of this point, whether the factory is organised for complete continuous or flow production or for the volume production of a variety of products on a flow basis, the planning, including the organisation and synchronisation of materials, machinery and man power in such a way as to get the best balance of plant utilisation, is complicated. It is not a thing which can be constantly modified because of fluctuations in the idea of the production flow required or because some Department has failed to renew orders in sufficient time to permit the mass of detail involved to be revised.

It is, in fact, utterly wrong where big volumes are concerned to talk of orders of some fixed quantity of the product. It is necessary to talk of the RATE of production which is being ordered with some

reasonable indication of total duration. Manufacturing organisations laid out for volume production must talk, think and act in terms of daily, even hourly, flow of materials and work throughout the whole organisation. For example, if aero engines are to be produced at the rate of 65 per week with a working week of 130 hours (giving a unit time of two hours per engine) then all stages of production from inward flow of raw materials through machining operations to final completion of the product must support a flow equal to that unit rate. Actually, the " manufacturing interval " between the receipt of instructions and the commencement of delivery will be controlled by those items which take the maximum fabrication period and, unless steps are taken to avoid it, this manufacturing interval, which is usually a period of six months or more, will inevitably recur every time a fresh order is placed. The repercussions of such gaps in output are serious, not only because of the direct loss in products but because of the enormous wastage of productive capacity and the time of skilled labour which is involved in reorganising every detail of the factory because of the interruption of the production flow.

Reverting to our example of the production of aero engines, it is desirable that the factory concerned should not receive instructions to make, say, 1,000 aero engines but that it should be ordered to proceed with the manufacture of 65 engines per week until further notice. Some guidance, of course, must be given as to the probable total duration of this rate of production.

Supply Departments issuing orders on such a scientific basis would be in a position to know at all times the amount of their maximum commitment in raw materials and in components in course of manufacture since the manufacturer concerned would organise his investment in materials and parts in such a way as to suppport the output of 65 per week. It might be found, for example that the support of such a production flow would involve a stock of raw materials equivalent to 12 weeks consumption and a stock of components equivalent to 8 weeks consumption and the Supply Department concerned would be assured that if immediate cessation of production were at any time needed, these figures would represent the limit of its possible responsibility for incompleted work. Immediate cessation of production is, however, an unlikely contingency since, if new designs are to be introduced, the time taken tooling up will always exceed the time it would take to " work out " stocks of materials and parts for an old design. We append to this memorandum a chart illustrating in a graphic manner how ordering on a fixed batch system so often causes loss of production due to lack of appreciation of the fundamental manufacturing interval which should govern the notice given of continuation, and we strongly recommend that firms handling big volume production should

receive instructions in the alternative manner outlined above. We are firmly of the opinion that only by the adoption of this system can raw material supplies, plant availability and man power be calibrated to give constant delivery of the product at the right time and in the required volume to meet a given programme. At the same time, this system makes available at all times a clear cut picture of the investment in materials and parts in progress so that the effect of any projected increase or decrease in output or even a complete cessation of manufacture can be quickly visualised and steps taken in sufficient time for its liquidation.

That steps should be taken to Set Up Capacity Exchanges on an Area Basis to Link Up Overload with Spare Capacity.

We are aware that recommendations along these lines have reached you from other sources and, in including this recommendation in our memorandum, we do so with the object of lending all support to these suggestions and to enable us, as men in charge of works throughout the country, to recount our personal experiences *vis-a-vis* the existence of spare capacity.

Since our Committee has been in existence we have been successful in running our own Capacity Exchange as between firms employing our members, and the experiences we have gained in doing so enable us to make the following statements—

(1) Hardly any firm is equipped in exact balance with its war-time production. The unbalance, however, is constantly varying, and the space capacity comes into existance week by week, and does not consist necessarily of the whole time of certain machines. It frequently consists of blocks of time for different machines and their skilled operators, which can only be taken up by the existence of Exchanges which are right up to date almost daily in their information and exchange facilities.

(2) Those Area Boards which are most efficient are frequently informed by firms that spare capacity exists but never seem to be informed when it has been absorbed. Consequently, in writing to firms notified as possessing spare capacity one more often than not finds it no longer exists.

(3) It is no use running Capacity Exchanges based upon just the names of the machines concerned, i.e. centre lathes, mills, drills, etc. It is also necessary to know the grade of limits to which the plant can be worked, its speeds, the existence or otherwise of measuring equipment, and other technical particulars. These would be best handled by production technicians on the basis of sufficiently small areas for personal knowledge to exist of the firms involved. There could, of course, be interchange between areas.

(4) There is no question whatever in our minds that spare capacity does exist on a large scale. However, it does not frequently take the form of large blocks of capacity in one factory which would correspond with the load represented by a complete product nor, as a rule, does it take the form of definitely spare and transferable machines. In every firm there are machines, sometimes in fair numbers, which are essential to the products of the firm but which, through the unbalanced load, are not fully loaded. Such spare capacity can only be picked up by sub-contracting from a firm acting as the parent firm on the main contract, and only then if really practical Capacity Exchanges are available which are up to date in their records.

(5) We wish to suggest quite seriously the possibility of the use of radio on a wave length specially assigned for certain hours of each day for broadcasting details of capacity required. In dealing with difficult bottlenecks surely a scheme would be worth a trial? A typical item broadcast might be, for example:

"FIFTY HOURS THREAD MILLING REQUIRED FOR 1¼ IN. DIA. STEEL BY 3 IN. L.16 T.P.I. R.H. HOBS AVAILABLE, CLOSE LIMITS"

or—

"INTERNAL GRINDING CAPACITY REQUIRED 50 HOURS WEEKLY TO SWING 16 IN. D. 12 IN. BORE BY 8 IN. LONG, CLOSE LIMITS."

THAT THE MEANS NOW BEING ADOPTED FOR THE DUPLICATION OF PRODUCTION FACILITIES SHOULD BE REVIEWED.

It is realised that considerations of safety involve the provision of alternative means of production for each important product at the present time, and it is usual for these alternative means to consist of the complete duplication or multiplication (sometimes over five or six firms) of the complete equipment for production.

We believe that this rule is too slavishly followed and is extended to products which it is, in any case, very easy to get, and for which the work involved in setting up duplicate production facilities is immensely greater than appears to be justified by the circumstances of the case. The following points are made in support of these arguments—

(1) The setting up of duplicate facilities involves the work of skilled toolmakers in order to make duplicate tools. The alternative of running off quantities of the product from the tools already in existence and holding these in store would sometimes prove a far cheaper method of providing the safeguard and would not involve work by skilled toolmakers.

(2) Contract Departments have a habit of accusing a manufacturer of greed when he suggests that he should run off the whole of some requirements for which he possesses the equipment and which he could undertake very cheaply and quickly. Frequently the setting up of a duplicate provision will involve the country in thousands of pounds, and the loss of a great deal of time and skilled labour, and the case is rather one of efficiency than greed. It is believed that there is far too much sub-dividing of orders. Long runs spell efficiency and short runs, caused by sub-dividing of orders, spell wastage of skilled labour as well as of tools, machines, and materials.

The above proposals summarise, in our opinion, the most urgent of the problems which are being experienced by production men. We urge their serious consideration, and we request that facilities be granted for a small deputation from our Council to wait upon you as soon as possible in order that a further explanation of these matters may be given.

J. E. Blackshaw, Engineer and General Manager, G. D. Peters & Co. Ltd., Slough.

G. H. Hales, Engineer and Managing Director, Geo. H. Hales Machine Tool Co. Ltd.

F. W. Halliwell, Engineer and Managing Director, Arnott & Harrison, Ltd.

B. C. Jenkins, recently Production Engineer, Vauxhall Motors, Ltd.

E. J. H. Jones, Works Manager, A.E.C., Southall.

N. V. Kipping, Works Manager, Standard Telephones and Cables, Ltd., New Southgate.

W. S. Puckey, Works Manager, Hoover, Ltd.

J. D. Scaife, Engineer and Managing Director, John Lund, Ltd.

THE MANUFACTURE AND USE OF CEMENTED CARBIDES

Paper presented to the Institution, Sheffield Section, by H. Burden, B.Sc.

How uniformity and specific physical properties of cemented carbides are obtained is explained in this paper. The author has taken care to differentiate between various types of cemented carbides and has clearly illustrated their respective applications. The problems of fixing tips to their shanks are discussed and the economic and practical limitations of the use of carbides are mentioned.

THE basis of all cemented carbides has been and still is tungsten carbide. It was discovered by Moisson during his researches with the electric furnace in 1886, and he described it as a black lustrous, hard, brittle and coarsely crystalline compound. For thirty years the material remained a curiosity, and this is not surprising. I have prepared carbide by Moisson's method, and if any of you were to compare such a product with the cemented carbides used to-day, it is doubtful if you would associate the two. The work on this compound was revived when a substitute was wanted for diamonds for wire drawing, particularly for the manufacture of tungsten filaments, and it was natural that tungsten carbide should be tried. Made in the modern way, tungsten carbide had entirely different properties from the Moisson product, and a further improvement was effected by the addition of what is now known as a " bond metal " which gave the material a degree of toughness. The process was developed in Germany and very soon afterwards in the United States where a great deal of attention was paid to carbides of metals other than tungsten.

The method of manufacture of cemented carbides calls for the presence of two distinct constituents. Firstly, an intensely hard compound which will remain essentially stable and infusible at all heat-treatment temperatures, and secondly, ductile metal or alloy of comparatively low melting point. The constituents are prepared in an intimately mixed powdered form, are pressed into a block, and are then heat-treated at such a temperature that the second constituent, that is the softer constituent, bonds the harder into a compact mass.

Whilst on the face of it there appears to be a large number of metal alloys and other compounds such as carbides, borides, and nitrides which may be employed in the manufacture of these alloys,

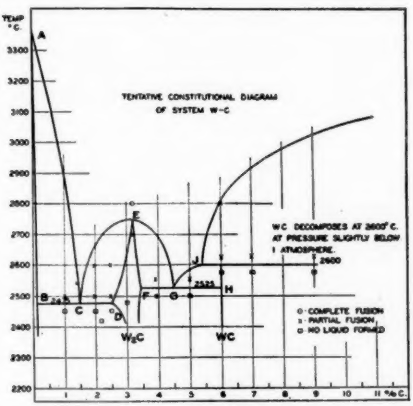
actually the selection of suitable constituents is limited for several reasons, some of which will be explained later. The first hard metals containing tungsten carbide and cobalt are still most generally used, and constitute the bulk of the commercially produced hard metals. Whilst a number of other metals such as tantalum and titanium are employed, they are used chiefly in small percentages as addition elements to the tungsten carbide cobalt hard metals.

There are two methods of manufacture—the cold press and the hot press process. The cold press method is almost universally adopted. In this method the tungsten is first converted into carbide. This carbide is then broken down by crushing, and is mixed with cobalt in a ball mill for a predetermined period. The resulting mixture is an exceedingly fine powder which is pressed into blocks of suitable size and shape for the production of tool tips. The pressing is done in hardened steel dies at pressures which vary considerably, from as little as three to as much as 100 tons per square inch. Although these blocks may be handled quite readily at this stage, they require some shaping to their final form, and it is desirable that further toughening be carried out before this shaping takes place. Usually a semi-sintering operation is carried out. This is accomplished by heating the blocks in a reducing atmosphere such as hydrogen to the pre-sintering temperatures. Heat treatment at lower temperatures may be carried out if a high boiling point bond such as glycerine is present to accomplish the same end, but it is believed that this is not so satisfactory as the method of semi-sintering. The blocks of the material at this stage resemble chalk or graphite, and whilst they may easily be cut to shape, they are sufficiently strong to be handled with ease and to enable sharp edges and definite forms to be given to them. The shaping is carried out on abrasive wheels on special machines, and when shaped the blocks are ready for sintering. It is essential that they should be shaped to within fairly close limits of their intended dimensions since after final sintering, grinding is the only method of altering the form. The tips are now placed carefully in refractory crucibles and are subjected to a critical high temperature for a time which may vary from fifteen minutes to two hours, depending on the properties required of the alloy. The rate of heating and cooling from the sintering temperature affects the products, and in all cases is precisely controlled to give definite characteristics. After this heat treatment the tips are ready for use. Many variations of this process have been devised to get over some of the inherent difficulties which occur and to produce products with modified characteristics. For instance in the manufacture of an alloy containing only 3% cobalt and 97% tungsten carbide, it is extremely difficult to ensure the even distribution of the cobalt. One method that has been proposed to accomplish this is to electroplate the carbide particles with cobalt

metal, whilst another is to add the cobalt in the form of oxide or similar compound, which after being evenly mixed with the carbide, is reduced to metal by the application of heat in a reducing stream of gas. Such modifications as these give desirable characteristics in certain cases, but for the greater part the process is carried out as previously described. The hot press method, which is the alternative method for the preparation of cemented carbides is not used to-day and need not be considered.

Now it is convenient to consider the properties of the sintered product from three aspects. These are: (1) The nature of the constituents, (2) the nature of the structure, (3) the importance of the sintering process. With regard to the nature of the constituents, as I have already stated, two essential phases must be present. Firstly, an intensely hard one and secondly a soft ductile metal,

TUNGSTEN-CARBON SYSTEM



Constitutional Diagram of Tungsten-Rich Portion of the System Tungsten rbon.

Approximation of the Constitutional Diagram

Fig. 1.

and for our purpose we can consider these two to be tungsten carbide on the one hand and cobalt on the other. The properties of cobalt are, of course, well known. It is ductile metal of the iron group, and in the pure state shows a high tensile strength. Its M.P. is 1,454°C. and, as far as can be judged from the work already carried out, it appears that cobalt does not form a carbide.

Sykes has worked out the diagram of carbon and tungsten (Fig. 1). Carbide is there claimed to be formed by a peretectic reaction at

2,600°C. The hardness of tungsten carbide cannot yet be said to have been finally determined, but according to a paper by Ridgeway Ballard and Bailey, it has a hardness equivalent to fused alumina. The following table shows their extension of Moh's scale of hardness, but on the evidence they give, the position of the metals on the hardness scale can only be considered to be approximate. The

MOHS SCALE	EXTENSION OF MOH'S SCALE	METAL EQUIVALENT
6 ORTHOCLASE	6 ORTHOCLASE OR PERICLASE	
	7 VITREOUS PURE SILICA	
7 QUARTZ	8 QUARTZ	8 STELLITE
8 TOPAZ	9 TOPAZ	
	10 GARNET	
	11 FUSED ZIRCONIA	11 TANTALUM CARBIDE
9 SAPPHIRE	12 FUSED ALUMINA	12 TUNGSTEN CARBIDE
	13 SILICAN CARBIDE	
	14 BORON CARBIDE	
15 DIAMOND	15 DIAMOND	

hardness of the cemented carbides must not be confused with the hardness of pure tungsten carbide, but evidence indicates that this hardness figure may be not less than, and may even materially exceed 2,200 diamond hardness. Thus, it may be seen that the hard constituent of the cemented carbides has a hardness greater by a 1,000 points on the diamond hardness scale than the hardest steel that can be made.

The structure of a cemented carbide consists of hard particles bonded together in a matrice of cobalt, and Fig. 2 shows a clear view of what it is like. The particular specimen photographed there is very coarse grained compared with most cemented carbides, for a clear picture could not otherwise be obtained. The dark phase is the cobalt matrice. *The sintering process* in the case of cemented carbides does not consist merely of a welding together of the particles of the pressed powder, and a more descriptive term which may be applied to the process has been given by Dr. Jones, who suggests the term fritting.

It has been established that tungsten carbide and cobalt react to give a very complex system, and this has been investigated by Takeda, the Japanese worker. He suggested an equilibrium dia-

gram, and the most noteworthy point advanced by him is the formation of the binary metastable eutectic containing about 34% cobalt. Thus, the sintering or fritting operation may be said to take place in its simplest manner in the following way. On heating the mixture of cobalt and tungsten carbide powders, some limited diffusion takes place with the formation of solid solutions. At the eutectic temperature, some of these solid solutions melt and wet the remaining particles. So we have a pasty half-molten mass. If the temperature is still increased more of the tungsten carbide dissolves in the cobalt to form an increasing amount of liquid. On cooling the W.C. is thrown out of solution to form angular grains. Finally,

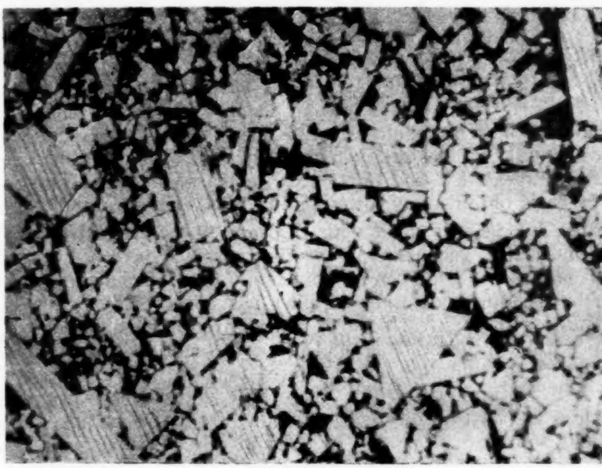


Fig. 2.

the remaining liquid solidifies at the eutectic temperature to form the matrix which bonds the hard particles together. The eutectic never forms, however, with the herringbone structure in the com-commercial alloys, since one phase, the W.C. is always pr cipitated on the main bulk of undissolved grains of W.C. This leaves the gamma solid solution as the bond. On cooling down to room temperature this solid solution throws out W.C., to leave almost pure cobalt as the bond. Thus, in spite of the complicated sequence of the reactions, the material finishes up as two almost pure constituents, oft cobalt on the one hand and intensely hard carbide on the other.

The sintering process in actual practice is not quite so simple as may have been gathered from my foregoing remarks. Thus grain-size may vary within wide limits if not controlled. Graphite may be precipitated if the material is not held in the metastable condition, while the rate of cooling may be such as to hold in solution in the cobalt an undesirable amount of the hard constituent. In practice, we find that it is necessary to control the rate of heating, the time at temperature and the rate of cooling, if the desired characteristics are to be obtained.

The appearance of the fracture of a carbide in which graphite has been allowed to form differs considerably from the appearance of a correctly sintered carbide. The rosettes can be plainly seen and such a carbide has a structure which might be compared with that of a grey cast iron. Naturally, such a carbide is very brittle, but a surprising fact is that even to-day many carbides are produced with such a structure. The above factors affect any given composition, and in addition, changes can be effected by varying the proportions of the bond metal and the hard carbide. Thus it has been found that the toughness, resistance to shock, and strength of the cemented carbides are increased as the proportion of the bond metal is increased, while brittleness, increased hardness and wear resistance is obtained by lowering the bond metal content.

So far, I have only dealt with W.C. and Co., as the hard carbide and bond metal, and while many other carbides have been investigated, no others have been so universally used. It has been found that the usefulness of other carbides has been chiefly confined to the addition of such carbides to tungsten carbide-cobalt alloys to produce in such materials special properties, and of these carbides, only TiC and tantalum carbide are used to any great extent. The field of application for these special carbides is, generally speaking, the cutting of steel as distinct from the cutting of cast iron and non-ferrous metals. It is found that all tungsten carbide alloys very rapidly develop a chip cavity on the upper surface of the tool, in a manner which is no doubt familiar to many of you from the examination of a worn high speed steel tool. This increases the effective top rake of the tool to such an extent that failure of the tool is very rapidly brought about. When Tic and TaC are added, however, it is found that this cavitation does not take place. The reasons for this are rather obscure, and whilst theories have been suggested which seem quite reasonable, there is room for further work regarding the matter. The view popularly held is that the hot steel cutting, as it passes over the top face of the tool, actually welds on to a particular grain of carbide. This result is the removal of a succession of particles which soon leads to the development of this cavity. This explanation also takes account of the fact that the cutting edge of the tools may remain unmarked while this cavity is

growing. Another theory postulates that it is due to the different heat conductivity of the two particular types of material, whilst yet a third suggests that the surfaces are essentially different in character, that of the straight tungsten carbide being rough, even in the most highly finished state which it is possible to produce commercially. It is, however, a fact that these alloyed hard metals do resist this cavitation to a remarkable degree, and where conditions are suitable it is possible for a carbide tool now to work for longer periods on steel than it will on cast iron.

In the development of the steel cutting carbides great difficulty was, and still is, experienced with some brands of carbide, owing to brittleness which is always associated with them. The cobalt content, for special reasons, has to be kept within narrow limits, and it is not possible to vary the hardness and toughness so readily as with the straight tungsten carbide cobalt alloys. Recent work, however, has shown that this disadvantage may to a large extent be overcome, and the successful machining of rough forgings, for instance, where the property of resistance to shock is of primary importance, is now an accomplished fact. Great care has to be taken with the application of carbide to this type of work to ensure that the correct grade is used.

The Manufacture of Tools.

The manufacture of the tools from the carbide tips has been well explained in the literature published by the various manufacturers of this type of product, and very little remains to be said. As is well known the carbide is used in the form of tips brazed on to carbon steel shanks. The brazing may be equally well done with copper, spelter, silver solder, or similar compounds. No special care is necessary other than preventing rapid temperature changes of the hard metal during the operation. The carbon content of the steel shank should be for normal purposes about 0.5 to 0.6%, but this composition is not essential. When brazing those tools it is not of great importance to ensure a very thin wall of braze metal between the shank and the tip. In fact, on the contrary, a reasonable thickness of such braze metal tends to some extent to absorb the stresses caused by the differential rates of contraction of the carbide and the shank material which occurs when cooling from the brazing temperature to the room temperature. Indeed such methods as the insertion of iron gauze, molybdenum sheeting, and others have been resorted to, in order to ensure that a sufficient cushion of braze metal is left underneath the tip.

The fabrication of special tools such as reamers, inserted tooth cutters, milling cutters, counter bores, and drills is best left to the makers of carbide alloys, the reason being that these are somewhat complicated jobs and may quite often be ruined in manufacture by

unskilled hands. Whilst troubles may easily be corrected by the carbide producer with special equipment, it is often a different matter in a shop with limited facilities for such work. Where, however, the shop is so equipped and the bulk of work merits such a procedure, it might be possible to buy the tips and build up tools in preference to buying the finished article. These remarks, of course, apply only to the special tools listed above, there being very little difficulty in the building up of ordinary turning tools, and any shop may undertake this work with confidence provided that the necessary care is taken.

Carbide manufacturers and manufacturers of grinding wheels have collected and published a large volume of literature relating to the grinding operation. There does seem, however, to be one feature which has not been exploited to its fullest extent, and that is the use of diamond grinding wheels. There is no doubt that the most economical method of reconditioning tools which have not been very badly damaged is by the use of a diamond wheel. It is only when a badly chipped or broken tool has to be re-ground that the coarse silicon carbide grinding wheel offers any advantage over the diamond. Wherever the volume of work is sufficient, the diamond wheel affords the cheapest solution of tool reconditioning with one exception. This exception is the grinding of forms on form tools. Since the diamond wheel cannot readily be shapped by any normal method it is oftèn better to use silicon carbide wheels for this work.

The Application of Carbide Alloys.

No single tool or tool material will perform equally well in all circumstances, and this is particularly true of carbide hard metals. The success of any job depends almost entirely on the correct selection of the type of carbide to do the work. Many shops to-day use only one or two grades, say one for cast iron and non-ferrous metals and one for steel cutting, whereas there are in fact many different types and grades available. Whilst in certain cases this may be the most economical arrangement, it is certain that in many shops a saving could be effected by a close investigation into this question of the correct grade for each specific set of conditions.

Before describing the application of different grades to the type of work met with in industrial practice, it may be of some interest to consider further the peculiarities of the physical properties of carbide tools in relation to the work which they have to perform. The hardness of cemented carbides on the diamond scale varies from about 1,300 for the soft tough alloys containing large percentages of cobalt to about 1,700 for the harder alloys which have been developed for such arduous work as the drilling and machining of glass, procelain, etc., while when greater hardnesses are required, there are experimental types available which have shown diamond

hardness figures well in excess of 2,000. A no less important factor is that cemented carbides retain their intense hardness at elevated temperatures in a most remarkable manner. (Fig. 3). This graph gives a comparison of the hardnessof cemented carbides with that of other tool materials at elevated temperature.

Such properties enable carbides to machine many materials which cannot be machined with any other tool. Examples of this are the machining of glass, porcelain, stone, slate, or even hardened tool steel itself, and the retention of hardness at high temperatures enables extremely high cutting speeds to be maintained. This extreme hardness is, however, accompanied by a rigidity which does not allow the material to absorb a great deal of shock before fracture, and this point must be remembered when applying the tools. They

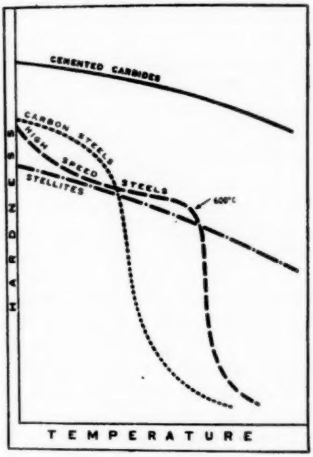


Fig. 3.

cannot be applied in the same manner as high speed steel tools. It cannot be too strongly emphasised that, whilst the application of these alloys is not difficult, it does necessitate a different technique from that required by other cutting alloys. Coupled with this absence of resistance to shock is the fact that in relation to the hardness the tensile strength and the shear strength are low, and this again introduces difficulties. It is found that if the tools are put to work at slow speeds with heavy feeds rapid destruction often results, and it is essential for success that these tools be worked at high speeds with comparatively fine feeds. Under these conditions the actual pressure on the cutting edge of the tool and the material

immediately behind it, is reduced to a safe level, and to obtain the necessary increase in the rate of machining advantage may be taken of the very high cutting speeds of which these tools are capable.

The next consideration is one of tool form. There are roughly speaking two types of chip or swarf which may form when metal is cut. The first is the segmented chip which is obtained when machining cast iron. Turnings of this material have a low shear strength, and break up into very small pieces as soon as the point of the tool enters the body of the work. These chips fly off and do not seriously affect the top surface of the tool. The pressure on the top surface is not unduly high, and it is found that cuts may be taken with a reasonably heavy feed on cast iron and similar materials without destruction of the tool. Whilst it is difficult to give a maximum figure it is believed that the feed should not be more than $^3/_{32}$ in. although instances have been recorded where this figure has been exceeded.

The second type of chip is the continuous type and is usually produced when metals of high ductility or shear strength are being machined. Examples are found in the machining of steel, copper, and some aluminium alloys. In the case of steel, the pressure on the top surface of the tool immediately behind the cutting edge is very high, and two methods may be used to reduce it. The top rake of the tool may be increased to a very high positive value, or the feeds used must be very fine, but as I have already pointed out, the steel cutting grades of carbide are relatively weak with regard to their hardness and it was found to be impracticable to increase the top rake of tools employing these grades. Therefore, it is necessary to employ very fine feeds when cutting steel with carbide tools. Thus, while it is possible to employ a feed of $^3/_{32}$ in. when cutting cast iron, a feed of only $^1/_{40}$ in. is permissible as a maximum when cutting steel. The recent development of new and stronger grades of carbide for the rough machining of steel has allowed the use of greater top rakes than have been used in the past, but generally speaking 3° to 8° is sufficient.

On materials other than steel, which give the continuous type of chip, large top rakes are quite common, but in these cases the stronger varieties of carbide should be used. Typical examples are the machining of aluminium and copper, where top rakes of 15° to 30° are employed.

The clearance angles on the tool call for little comment, and should in all cases be as small as possible. There is little or no advantage to be obtained in increasing the clearance angle above 6° to 8°, and quite often 4° is sufficient and gives excellent results. A large clearance angle serves no useful purpose and merely removes support from the cutting edge. The tool form is found not greatly to affect the performance of the tool. There is, however, one point which may

be noted. Sharp corners on the tool form should if possible be avoided, as the wear will in all cases occur more rapidly at such a point and hasten the destruction of the cutting edge. For the cutting of ductile materials the cutting edge should be straight, and should run into a small radius on the point of the tool. For the cutting of materials which give the segmental type of chip the shape of the cutting edge, whether curved or straight, does not exert a great influence on the cutting edge of the tool, although it may be found that a curved edge will in some cases prevent chatter and thereby lengthen the life of the tool.

While considering the form of the tool there is one other important feature which should be mentioned and that is the size of the tool and the support it receives in the machine. Vibration of any sort is one of the greatest foes of cemented carbide tools, and it should always be seen that the size of the tool employed on any particular application is sufficiently large. It is bad policy to economise on the size of shank. The size of tool employed should in general be as large as the machine will take, although there are exceptions to this rule when light work is being undertaken. The importance of absolute rigidity can be seen from the report of an American firm who received only two hours performance from a tip which was brazed on a shank of $\frac{5}{8}$ in. by 1 in. cross section. The same tip mounted on a shank $\frac{3}{4}$ in. by $1\frac{1}{4}$ in. cross section gave two days' performance, whilst on a still larger shank of 1 in. by $1\frac{1}{2}$ in. cross section it gave two weeks' service. This is, of course, an outstanding example, but it undoubtedly illustrates the importance of this point.

The set-up of a tool in a machine is also important. The tool box should be rigid in design and the tool should not be allowed to overhang from it more than is absolutely necessary. A tool shank projecting, say, $\frac{1}{2}$ in. may easily be deflected to the extent of a ten-thousandth part of an inch, whilst the same shank projecting 2 in. would deflect 64 ten-thousandths of an inch, an amount which would readily lead to the destruction of the tool. It can, therefore, be seen that the rigidity of the set-up may play an important part in deciding whether a carbide tool will successfully perform any given operation.

Carbide tools will work on any machine which is maintained in a reasonably good condition and which has ample power for the work which the tool will be expected to do. It is useless applying carbide to machines which are more or less obsolete, and which with high speed steel are taxed to the limit of their power, except in those cases where the material is so hard as to be unmachinable with any other type of tool. The degree of absence of chatter and vibration has, however, an important bearing on the type of carbide which may be applied. As a general rule the hardest grade of carbide which is available should be put on to any job provided the conditions are

so good that this carbide will not fail by chipping or spalling. This must be modified, however, where conditions are not too good and a softer, tougher grade is necessary. In every case there is an optimum combination of hardness and toughness which can only be determined by experiment. When a tool fails the type of failure should be carefully examined and a decision made as to whether the tool failed by spalling or by excessive wear. Care should be exercised since the cause may easily be mistaken. A spalled tool which has been cutting for a little while, for instance, may have all evidence of the actual spalling removed. In the case of a tool which has failed by wear, harder grades should be tried until evidence of spalling is obtained, and if the tool has failed by spalling a softer grade must be used. Cutting speeds on cast irons and non-ferrous metals vary from

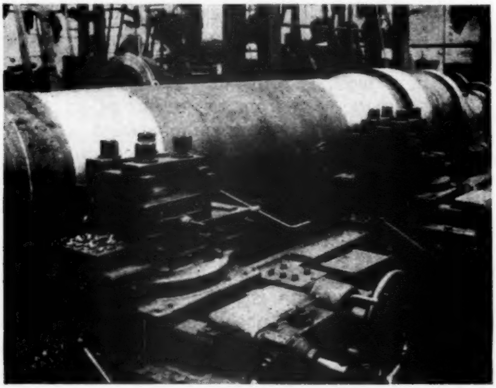


Fig. 4.

20 ft. per minute for chilled iron to about 600 ft. for finishing cuts on soft grey cast iron, while speeds up to 6,000 ft. are employed on some of the light alloys. Generally speaking, on these materials it usually pays to replace high speed steel tools with carbide. Rough machining may be accomplished with almost any depth of cut, providing the tool is sufficiently large, while scale, sand, or intermittent cutting does not present great difficulties. Fig. 4 shows a large cast iron flask being machined. The depth of cut taken was $\frac{3}{4}$ in. while the feed was $^{3}/_{32}$ in. per revolution. The overall length of this casting was 14 ft. and the diameter between 14 in. and 18 in., and it is interesting to note that the machining time was only four to six hours. The tools which worked at

speeds of 120 ft. to 200 ft. per minute could be used for several such jobs before regrinding was required.

The steel cutting carbides, while of more recent development are now made in a sufficient number of grades to suit many varied operations, and in Sheffield, at any rate, the use of this type of cemented carbide is of greater importance than the older type. It will be remembered that I pointed out how it was possible to vary the hardness and toughness of the tungsten carbide-cobalt alloys. In the case of the steel cutting grades, this is usually done by holding the cobalt content at a fixed value and varying the content of the special carbides such as titanium carbide or tanalum carbide. Thus the tougher grades for heavy duty intermittent cutting, etc., have a low percentage of titanium carbide, while tools for finish machining operations may have a titanium carbide content as high as 50%. Fig. 5 illustrates the machining of an alloy steel forging. The machine is a large Webster & Bennett boring and turning lathe,

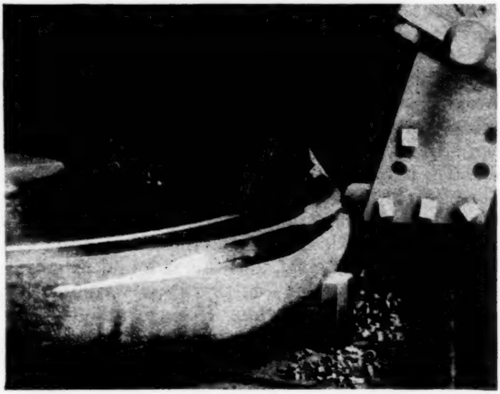


Fig. 5.

and it is admirable from the point of view of rigidity. The forging is of nickel chromium steel and it will be observed that the surface is extremely rough. The depth of scale on this forging is considerable ($\frac{1}{4}$ in. to $\frac{3}{8}$ in. in thickness). When using high speed steel it was found necessary to allow three or four shifts for the machining of one surface, but by using carbide tools the complete removal of scale and underlying metal, was accomplished in less than forty minutes, for a forging of roughly 30 in. in diameter On such a job as this the saving in labour costs easily covers the original outlay for carbide tools. In this particular case, the tool

which was of $1\frac{1}{2}$ in. square section took a cut of $\frac{5}{8}$ in., with a feed of $^{17}/_{1000}$th in. per revolution, and the speed roughly 180 ft. per minute. An interesting feature of this machine is an electrical attachment whereby the speed in revolutions per minute is increased as the tool traverses towards the centre of the work, thus maintaining a constant cutting speed. In machining such a forging, the shock resistance of tool must be high, and only a low titanium carbide content can be used. The wear on the carbide may be sufficiently rapid to destroy the edge of the tool in one or two hours, but even so, the use of carbide is very economical, because of the excessive time taken in machining by other types of tool material.

On repetition work such as is handled by automatic, turret, and similar lathes, the use of carbide tools gives a great advantage in that long periods may be obtained between regrinds. In the case of a set of carbide tools working on a small alloy steel forging turned in a No. 9 A Herbert lathe, cuts up to a depth of $\frac{3}{4}$ in. were taken and fine feeds were used. In this instance, the feed used was 160 cuts per inch, while the speed was just over 200 ft. per minute. Tools on these machines when working on black forgings usually work from three or four days to as much as a fortnight between regrinding.

In the case of black forgings, the tools have to withstand a certain amount of shock, and an alloy containing say 10% of titanium carbide is used. If, however, the tools are operating on clean metal, and particularly if the depth of cut is light, then tools with 20% or even more titanium carbide may be used.

On many automatic machines turning small diameters, difficulty is experienced with carbide in that the tool life will not exceed that of, say, a good high speed steel, and this is found usually to be due to the fact that sufficiently high cutting speeds cannot be obtained, and chipping of the tool edge occurs. However, the turning of small diameters with carbide has been successfully accomplished, e.g. on a small piece lathe, used for machining No. 1 and No. 2 morse taper shanks on drill blanks up to $^{13}/_{16}$ in. diameter, the speed was 3,000 revolutions per minute, the feed .009 in., and in spite of the uneven nature of the cut, for the tool had to cut through a weld, no trouble was experienced with chipping of the tool. The excellent design of the lathe, and the high speed which can be attained, are thought to be the reasons for this. The tool used is one containing 10% of titanium carbide.

The finished turning of steel may be accomplished at extremely high speeds, and the limit on steel of about 40 tons tensile would appear to be about 1,200 ft. per minute. Above this speed, which is obtained with a heavy flow of coolant on the tool, it is found that the heat generated underneath the turning as it comes away from the body of the material is so great that the stresses set up by the

intense local heating cause checking of the tool, and complete destruction of the cutting edge. In commercial practice speeds between 300 ft. and 600 ft. per minute are usually adopted depending to some extent on the depth of cut taken and the character of the material being cut. The finish turning of axles, spindles, cylinder barrels, and small shells are typical applications. The feed in all cases is very low, often not more than $^{5}/_{1000}$th in., whilst the cut is usually of the order of $^{20}/_{1000}$ in.

The amount of wear which occurs is important since such operations are usually carried out with a multiple tool set-up working on formers or guides attached to the tool box of the machine, and it is essential to maintain the position of these tools within accurate limits over a long period. Tools for this type of work may contain high percentages of alloying elements. Where exceptional rigidity is obtained tools embodying tantalum carbide in addition to titanium and tungsten carbides are found to be very effective. This type of work is always carried out on specially built machines, and the conditions on some machines are so perfect that a coin may be set edgeways on the back of the tool and remain in this position throughout the cutting operation. Massive headstock bearings, well designed lathe beds, the use of live centres and smooth high power drives are essential if these more highly alloyed carbides are to be used successfully. The installation of any such machine must necessarily be considered from the point of view of the output required, but providing a reasonable number of parts are to be machined, a saving can soon be shown in spite of the high initial cost.

When cutting at high speeds, there is a considerable danger to the operator from flying turnings. The logical solution is to so design the machine that the turnings fall away from the tool and away from the operator, and several high production lathes have been designed to effect this. However, in other cases, the tool producer has also the responsibility for controlling the turnings and this is effected by fitting a chip breaker. Several methods are used, and undoubtedly, the best I think is the one where a small groove is ground along the edge of the tool. It must be remembered, however, that in no case can a chip breaker be applied to a tool without its performance being adversely affected. The reason for this is because considerable work has to be carried out by the chip breaker in further deforming the chip, which results in excessive generation of heat at the cutting edge. Where such attachments are absolutely necessary these disadvantages must be borne, but where possible they should be dispensed with.

The field of non-metallic compositions offers great scope for the use of carbide, and here too the grade of carbide used is of the utmost importance. This may be appreciated when it is remembered

that both wood cutting tools and tools for the machining of porcelain insulators are typical examples of this work. The immense saving in time and tool costs is apparent from the following example. The operation was the drilling of a hole $1\frac{1}{8}$ in. in diameter in a moulded insulating composition used by a manufacturer of electrical components. The depth of the hole was 4 in., the time taken per hole was fifteen minutes when using a high speed steel drill, and the drill had to be reground three times in drilling one hole. Using a carbide drill the floor to floor time was reduced to four minutes, the speed of operation being 250 revolutions per minute with a feed of .012 in. The number of holes obtained between re-grinds was approximately 500.

The machining of materials such as slate, granite, and glass was demonstrated at an early stage in the development of this type of alloy, since it was natural that such sensational applications would draw attention to the material. To-day, many tools are used for such work, and it may be noted that carbide is now applied even in the form of inserts in stonemasons' chisels and such like tools.

In the field of wood working, modern mass production methods have called for wood cutting tools which would give longer service in the machines. The position here is complicated somewhat by the very keen edge which is required by these tools, and an included angle of 30° is often all that can be allowed. In addition to this the danger caused by flying fragments should the tool break, necessitates the use of the toughest possible grades of carbide, and the high cobalt alloys are generally used for this purpose.

I have endeavoured to reveal the characteristics of carbide alloys and the way in which these affect the method of use and application of carbide tipped tools. There is no doubt that many operations carried out to-day with high speed steel and similar alloys can be conducted much more efficiently with carbide tools, although this does not necessarily imply that with further development carbide tools will replace high speed steel for all purposes. Just as high speed steel at one time replaced carbon steel for certain work, and found a place for itself in industry, so has carbide established for itself a similar position for certain types of duty.

One of the greatest advances that has recently occurred is the production of alloys which are tougher and less liable to breakage than those previously obtainable. It is obviously an advantage to have a tool, which although possibly not giving in all instances the same life between grinds, is nevertheless, comparatively free from liability to damage by chipping or cracking, the chief defect in the early carbide tools.

With the extending use of carbide tools, machine tool makers have realised that they must keep pace by developing suitable machines, and most machine tool manufacturers now sell a whole range of machines which have been specially designed for use with carbide tools. Carbide tipped tools are, therefore, being more extensively employed where worn or obsolete machinery is being replaced by machine tools of modern design, possessing the rigidity and robustness of construction essential for their satisfactory use.

Discussion

Mr. Walker thanked Mr. Burden for his interesting paper and declared the meeting open for discussion.

Visitor : Can Mr. Burden tell me what steps are taken to ensure uniformity of structure during the manufacture and what guarantee have we ? I ask this question because, during the subsequent machining operations cracks are often blamed on to the grinding, which are mostly started in the actual manufacture.

Mr. Burden : Actually, in the manufacture great care is taken to ensure uniformity. First of all the raw materials themselves are as pure as it is possible to make them, more or less regardless of cost. Then, not only the purity but the grain size of these materials are very carefully controlled and then mixed under conditions which leave no doubt that the material is perfectly homogeneous. This can be tested quite readily by taking smaller and smaller samples and having them carefully analysed, and looking for the percentage of cobalt present. In that way, we do take great care that the material is uniform.

With regard to the cracking, that will have to be blamed on to the brazing, and the grinding subsequently carried out. Cracking does occur in sintering, but there is a very characteristic fracture which you can always detect afterwards, and I think that about 90% of the cracking which occurs in Carbide tools is due to brazing or grinding. As I mentioned, the rate of expansion and contraction of Carbide and Steel are widely different, and that can lead to very severe stresses in the Carbide tips after the brazing operation. These stresses are the cause of cracks in the grinding operation.

Mr. Gilfillan : I think Mr. Burden will agree with me when I say that this steel is still in its infancy. We do not know all the uses it can be put to. We have seen tonight the advantages and uses of it, but frankly I should have been better satisfied if the disadvantages of this steel could have been shown, which outweigh the advantages. The illustrations which have been shown have been on small piece work. What we want to know is, what are the advantages of using cemented carbide steel when you get, say, a shaft 12 ft. long. Can you get the same results, with the same speed and feed, as high speed steel ?

I would also like to know the definite relationship between the diameter of the work and cutting-speeds. If you take a shaft 1 ft. diameter and cut it at 500 ft. can you take a 3 ft. diameter shaft at the same cutting speed ? Surely, when you are using cemented carbide tools, more power is absorbed and if you can remove the

same weight of material with the ordinary high speed steel tool in the same time or within a given time, it is an advantage to use high speed steel for certain classes of work. Also, many suppliers of cemented Carbide tools say that it should be $\frac{1}{8}$ in. from the centre, others say that it should be on the centre and so on. Then, what advantages has cooling on this tool. Has it any ill-effect ? Some Americans particularly advocate cooling with copious supplies of graphite solution in some cases.

MR. BURDEN : Talking about the disadvantages, while they are there, and while we are probably more fully aware of them than most users of the tools I am sure they do not outweigh the advantages.

With regard to big work, providing you can get the cutting speed and the power with the machine you are using, I do not think there is any limit to the size of work you can tackle. However, I don't think there are many big machines used in Sheffield which have sufficient power to enable Carbide tools to be used economically. They are fitted with motors which will just do the work required when using high speed steel tools, they did not anticipate having to use, say 5 or 6 times as much power when cemented carbide tools came along, and this is one of the big reasons why the use of carbide tools is not more universal on big work. Another thing is that some of the forgings cannot be run at carbide speeds in many of the machines I have seen, without the machine being brought up out of its foundations. Unfortunately the forgings are not concentric and it is preferable to cut speed down in some cases and, under these conditions high speed steel will continue to be used.

Now with regard to the rate of removal of steel—it can be effected at about the same rate, either with high speed steel or with carbide With high speed steel it is done by an extremely heavy cut, whereas with carbide we take advantage of the high speeds which can be employed and use a fairly light feed. However there are many conditions which dictate either the speed or the feeds or even the depth of cut, and these factors are often the determining factors as to whether high speed steel or carbide should be used. There are many jobs where high speed steel is just as effective as carbide. With regard to the position of the tool, whether it should be on or below the centre, I think the best thing to do is to put it on the centre and alter the angle until you get the tool working properly. If you put it above or below centre, it is merely altering the clearance angle, etc., and this should be done by grinding. If the tool is above centre and the tool box is not rigid then there is danger of the tool moving into the centre of the work and causing subsequent failure of the tool. I think the best thing to do is to keep it on centre and correctly grind the cutting angle for the particular work you are doing.

With regard to the coolant, I think it is better that a heavy flow of coolant be used on the tool. You should always use a very heavy flow, a drip is worse than none at all. If you are going to use a tool without a coolant and it is going to do heavy work, a very useful tip to remember is that it will very rapidly get hot, and it is therefore advisable to heat the tool slightly before starting.

MR. TOWNSEND : Does not the cutting of the lengthy job depend not only on the rigidity of the machine and on the tool, but also on the resistance of the work-piece. The work, it appears to me, must be adequately supported along the whole of its length. It has always appeared to me that with a machine with a Vee bed or an inverted Vee bed, the tool has a longer life, whatever the job, than with a flat bed with jibs on the side where there is a possibility of backlash. I would also like to know whether, in the lecturer's experience, he has been able to successfully drill holes with a carbide tool.

MR. BURDEN : The resistance of the job in the case of long shafts is just as important as the rigidity of the machine. I once tried to machine a shaft of rather hard material about 4 in. diameter and 12 ft. long and I can say that it was a very bad job indeed : We took as long to machine it as we would have taken with a high speed steel tool. Fortunately, jobs of this sort do not occur too often. With regard to the Vee beds and flat beds I do not think that my experience is sufficient to justify my giving you preference for one or the other. Personally I think the Vee bed is the better one but we have a lathe which we use for testing purposes and it has a flat bed. It is an exceptionally good lathe for the job and is extremely rigid.

Drilling holes is rather a sore point. The carbide tip, as I have explained, has a low shear strength and this gives a very weak centre to the drill : the point of the drill twists off and it is found that it is almost impossible to drill soft ductile materials. On the other hand for hard materials, particularly abrasive materials, carbide is very successful for drilling even when the hardness is as high as 500 Brinell. As an example we supplied a drill for drilling insulating material and it had to drill a hole 4 in. long and $1\frac{1}{8}$ in. diameter. With a high speed steel drill, the drill had to be ground three times per hole, but with carbide, we managed to get 250 holes between regrinds. However, for drilling soft steel or even soft cast iron, it is better to use a high speed steel drill.

MR. PIGGOTT : I have one trouble in using carbide tools and that is, intermittent cutting on say, 12/14% manganese steel, where testing material has been cut off a ring—even on a mill built for carbide work. We can do turning and boring very successfully, but when it comes to cutting off excess material—we find that we cannot get any life at all from the tool, and in using a parting tool

it doesn't stand up very well. Could you give me any help on that point.

Mr. Burden : With regard to the intermittent cutting, that can be accomplished, providing it doesn't transmit too much shock to the tool : there is a limit to the amount of shock the carbide will stand and usually if the lathe is of very rigid design, it is possible to modify either the tool angles and the grade of carbide or your cutting conditions and to get quite a reasonable performance. with regard to the cutting angles, it is usually necessary to employ either no top-rake or negative top-rake : the cutting speed should not be too high, otherwise the shock is too great for the point of the tool. With regard to the parting tools and the material you mention, it would be an extremely difficult job, but it will depend to some extent on the actual width of the parting tools : if they are narrow it is quite impossible to get the rigidity necessary, and under such conditions fracture of the complete tool is usually the cause of the failure. If you get a reasonable width, say, $\frac{3}{8}$ in. or $\frac{1}{2}$ in. at the cutting end of the tool, when it should be a successful operation.

Visitor : With regard to the grinding of carbide tools, certain manufacturers recommend grinding wet and others grinding dry. I wonder if there is any reason for this and if so, which should be ground wet and which dry ?

Mr. Burden : With dry grinding and particularly hand grinding, you have to grind very slowly, otherwise the tool gets too hot to hold, and you therefore have to treat the carbide with great care. Generally speaking, if the carbide makers recommend that that carbide is to be ground dry, it is because that carbide is extremely brittle and has to be handled with great care. Dry grinding is the method of ensuring that it shall be given care. Wet grinding is preferable because it is faster and the only proviso is that a copious flow of coolant is used. Wet grinding is, I think, preferable for all grades of carbide. The only reason for recommending dry grinding is, as I explained, that the manufacturer wants you to use great care with that particular carbide.

Mr. Fidler : I am not going so far as to admit that there are cases where applications are not beneficial but on certain heavy forgings we have recently been carrying out tests with cemented tools, and one fact that strikes me as difficult to get over is that in taking a reasonable job (7 or 8 ft. long) in a perfectly new lathe, we were quite successful in getting results with this particular cemented carbide tool, but when you come to analyse the results (which were accurately recorded in this case), you have to get an extra labourer to carry the scrap away and the delay caused is wasteful. Carbide tipped tools are very expensive ; and the cuttings themselves are inconvenient to handle. There is a larger field in industry for carbide tools than originally partly because if the cutting is inter-

rupted you don't often get these long troublesome cuttings to deal with. It is possible to use a chip breaker on the tool, but I have seen them worn away within a quarter of an hour, and you are practically back where you started. Now you have less brittle Carbide tools, you can do very well with nickel chrome of the 70 ton type but I should not like to machine it if over 100 tons. I am only speaking about normal jobs and I should like to know what grade of carbide one should ask for to stand up to such conditions as those I have mentioned.

MR. BURDEN : With regard to the job you first mentioned I think the economic use of carbide tools, to some extent, depends on the trouble which is taken to get the conditions suitable both for the operator, the tool, the machine and so on. For instance, you mention that it is essential to have a labourer to remove the turnings. If you are going to remove the turnings, faster from the job, steps must be taken to remove them from the machine. With the modern carbides there is no reason why these turnings take up undue space, and often it is not necessary to put a chip breaker on to get these turnings to curl up or actually break off the job in short pieces. It can often be done by correcting the tool angle. As to the chip breaker the one I prefer will turn back the turnings on to the job and very effectively break them off—that is the one I emphasized—one ground on the tool itself and to which I referred in my lecture. You don't have a great deal of trouble with the chip breaker being worn away, since the cutting edge goes first.

With regard to the cutting of the 100 ton nickel chrome steel, I haven't had a great deal of experience machining such high tensile steels, but what I have had indicates that some of the modern grades of carbide would quite successfully do such work : usually the grade recommended for fairly rough work is the one you should employ on nickel chrome steels, particularly when they are hardened to a high tensile strength.

MR. FIDLER : Why a grade for rough work ?

MR. BURDEN : The reason is that nickel chrome steel does not have the same tendency to form a chip cavity that the mild steels have, particularly when the former are hardened to a high tensile strength, and you can therefore use a steel cutting carbide which hasn't a very high percentage of titanium or tantalum carbide This gives it a greater shock resistance.

MR. GILFILLAN : Can you give us some recommended feeds and speeds ?

MR. BURDEN : Not too low, the tendency is always to drop the speed. I should think not lower than 100 to 120 ft. per minute while the feed should not be more than about 0.017 in. with the depth of the cut dependent on the size of the tool.

VISITOR : During your lecture you mentioned copper as a brazing

agent for tungsten carbide alloys. Is there any special virtue in copper ? For instance, trouble is often experienced due to scaling of the shank if it is for a tool, when taken up to the temperature at which it is necessary to braze with copper. Why take a tool up to the neighbourhood of 1200°C when it can actually be brazed with silver solder at about 850°C. or lower temperatures. Also there is one application—possibly the oldest—for tungsten carbide, which I was rather sorry you did not mention, and that is, wire drawing dies : there you have very extreme temperatures. The inside of the die, which is actually doing the drawing, will attain a very high temperature whereas the outside is water cooled. Would the brazing agent there have no effect on the transmission of heat from the die ?

MR. BURDEN : The chief reason for using copper is that the tool in use often gets up to quite a high temperature. You don't always know if there is going to be a copious flow of coolant which is recommended, and it is a safeguard against the brazed material being softened by the heat. That is, I think, one of the main reasons for the use of copper. In addition to that it gives a fairly good bed underneath the tip and absorbs to quite a good degree the stresses which are set up when the tool cools down from the brazing temperature. With regard to the use of silver solders, the objection to their use is chiefly that the melting point is not high enough and you run into danger of the brazing material softening when the tool is actually doing the job. The solder referred to, melting at 850°C. is quite good and has a high strength up to 600°C. but silver solders are, I am afraid, only suitable for very light work.

With regard to the question you raise about wire drawing dies, it is quite true there are extremes of temperature. The outside of the die is water-cooled and the inside temperature is very high but the effects are counter-balanced by using a grade of carbide which is strong enough to stand up to it. This is done by increasing the cobalt content. The effect of the brazing material on the transference of heat from the carbide tip to the water-cooled casing, I don't think need be seriously considered, more depends on using the right grade of carbide for that particular job. The main point anyway, is that the brazed joint should be perfectly sound and not filled with blow-holes.

VISITOR : Mr. Burden stated that the grinding of the chip breaker in the carbide tool could be accompanied by " cratering." I should be pleased if Mr. Burden would give us some reasons for that.

MR. BURDEN : One effect of the chip breaker is, by bending the chips, to increase the amount of heat generated at the cutting edge. Then the tool is liable to failure through " cratering " and you can possibly blame the chip breaker for that.

VISITOR : You think that the trouble is " cratering " due to the heat generated, not to the friction or pick-up or pressure ?

MR. BURDEN : Well, pick-up which is dependent, amongst other things, on the pressure.

VISITOR : The pressure is greater in the " crater " than it is on the cutting edge ?

MR. BURDEN : Yes.

VISITOR : Some mention was made of brazing agents including silver solder. It is my experience that silver solder has no affinity to tungsten carbide. Can you tell me whether that is, in your experience correct ?

MR. BURDEN : It depends, to some extent, on the type of carbide with which you are working, but it is, generally speaking, a question of getting the surface clean. To clean the surface of the carbide thoroughly with the flux at the brazing temperature is quite a difficult job. but the higher the temperature, the easier it becomes. If you use a flux such as borax, the flux only becomes effective at 900°C. and begins to dissolve oxide when you get to the brazing temperature. On the other hand silver solder melts below 900°C. and it is necessary to use a special flux, under these conditions, when you can very effectively use silver solder from the point of view of obtaining a coating of the brazing metal to wet the tip.

VISITOR : I am rather surprised we haven't heard some of the advantages of the use of carbide on, say, rolls. A very good example is to be found in America, for instance, where carbide rolls of fairly large dimensions are being used, and I should have thought that would have been of particular interest to Sheffield people, particularly with regard to the production of sheets—stainless sheets and so on, when fine finish is necessary.

Some people are using wire drawing dies on hardened steel and in the first place they tried three obtaining very good results : the next three on the same class of steel, were not quite so uniform. That brings me again to the question—how is this material graded ? That, I think is of general interest.

MR. BURDEN : First of all, with regard to the rolls I believe there are some in use in England : they are made by an American firm and their method of manufacture is an extremely complicated one, employing some very expensive machinery and so far, I don't think there are any British manufacturers actually making carbide rolls. The largest rolls are about 4 in. diameter and somewhere about 18 in. long and are used chiefly in the production of highly-polished stanless steel sheets.

With regard to the non-uniformity of wire-drawing dies this actually opens up quite a large field for discussion. The testing of the carbides is quite a specialised job. Actually we have no difficulty once we have worked out conditions to say, test the hardness

of any grade, but you have to go to a lot of trouble at first both in determining the load to use and how to apply it. The hardness of any one grade is held within one point on the Rockwell A Scale. The non-uniformity in the case of dies would be due to many things other than hardness. It is very difficult to make die pellets of carbide without some degree of porosity in the centre and since you have to use the centre for drawing dies it is necessary to take very great care in the manufacture of these pellets. It is possible to produce pellets for dies without porosity in the centre, but it if is not looked for specially, then trouble would be encountered.

The meeting was closed by a vote of thanks to Mr. Burden, proposed by Dr. Clarke, and seconded by Mr. Gilfillan.

THE REBUILDING OF OLD MACHINE TOOLS FOR THE REQUIREMENTS OF WAR.

By Dr. G. Schlesinger, Director, Research Department.

SPEED is the watchword! The simplest means of increasing the efficiency of the workshop seems to be the introduction of super-rapid tools (5 to 15% cobalt, 18 to 20% tungsten, 1 to 2 vanadium) or stellites,or cemented tungsten carbides in order to replace the ordinary high-speed steels (18% tungsten) which can no longer compete with the modern tools. This introduction, however, is impeded mostly by the weakness of the old machines which do not allow the application of the high speeds which are necessary for the exploitation of the modern tools, and are not so designed that they can be run at high speeds without showing detrimental, even dangerous vibrations, which ruin the tools. The example of a more

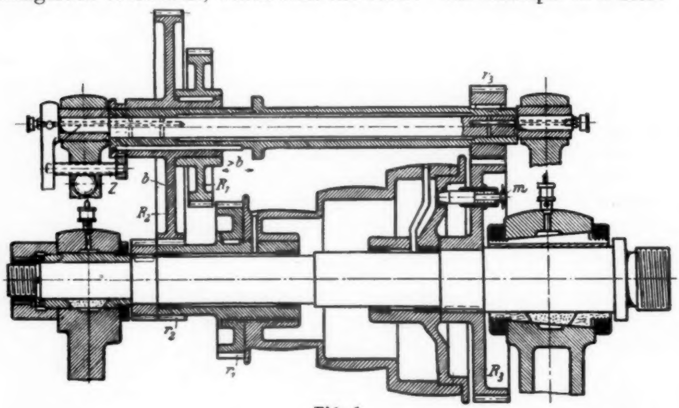


Fig. 1.

than 25 years old lathe of 22 in. swing, 4 h.p. cone pulley belt drive, will show the way in which successful rebuilding can be achieved to make the aged machine useful for up-to-date manufacturing. This is an indispensable requirement if we intend to use all existing machine-tools to the utmost to-day for the need of war, and later for peaceful work, too. The fast headstock of the lathe, Fig. 1, had nine speeds, three directed by the cone pulley, three by the medium back gear. $\frac{r_1}{R_1} . \frac{r_3}{R_3}$, and three with the low back gear $\frac{r_2}{R_2} . \frac{r_3}{R_3}$.

The table, Fig. 2, shows a comparison of the old range of speeds with those of the rebuilt machine. The maximum speed of 250 was increased to 500 r.p.m. The belt of $3\frac{1}{2}$ in. width on the counter-shaft was increased to 5 in. width, and runs now at a speed of 1,600 ft. per minute, instead of 800 ft. per minute. The belt from the counter-shaft to the cone pulley was increased from $3\frac{1}{2}$ in. to

SPINDLE SPEEDS

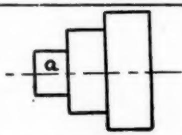
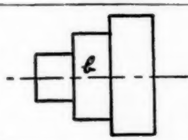
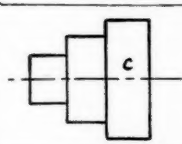
	Old Machine			Rebuilt Machine		
	Direct	Medium gear	Low gear	Direct	Medium gear	Low gear
		$\frac{r_1}{R_1}\times\frac{r_3}{R_3}$	$\frac{r_2}{R_2}\times\frac{r_3}{R_3}$		$\frac{r_1}{R_1}\times\frac{r_3}{R_3}$	$\frac{r_2}{R_2}\times\frac{r_3}{R_3}$
	250	78	23	500	156	46
	166	52	15	332	104	30
	112	36	10	224	72	20

Fig. 2.

4 in. width ; the step itself was $4\frac{3}{8}$ in. wide. Both belts run now on the hair side and are well greased !

They could therefore transfer 12 h.p. instead of 4 h.p. In addition, the quick-running belt has a better efficiency. By raising the speed we only gain power, the cutting *forces* remain the same, the chip area cannot be much increased with regard to the strength of the cast-iron bull-wheel.

A good belt ought to run at at least 26 ft. per second, which represents a very good and reliable speed. We got this high speed

LATHE CHARACTERISTIC : SPEED OF MAIN SPINDLE R.P.M.

Dia. of piece d. in.	Circum. πd. in.	20	30	46	72	104	156	224	332	500
½	1.6	2.7	4	6	9	13	21	30	45	67
¾	2.4	4	6	9	14	20	31	45	67	100
1	3.2	5.5	8	12	19	27	42	60	90	133 III
1.5	4.75	8	12	18	28	41	62	89	133	197 IV
2	6.3	I 11	16	24	36	53	82	118	176	262
2.5	7.9	13	20	30	47	68	103	147	221	327
3	9.4	16	24	36	56	81	123	175	263	390 IV
4	12.5	21	32	46	74	108	162	234	350	520
5	15.8	26	40	60	94	136	205	294	442	658
6	19	32	48	72	113	163	240	355	532	790
7	22	37	55	84	130	190	285	415	618	915
8	25	42 I	62	95	147	217	325	468	700	1035
10	31.4	II 52	78	120	185	272	410	588	880	1300
12	38	63	95	145	225	329	492	705	1060	1575
14	44	73	110	167	260	382	575	820	1230	1820
16	50	83	125	190	295	434	650	930	1400	2080
18	57	95 II	142	218	336	492	740	1060	1600	2360
20	63	105	160	242	380	545	818	1190	1790	2660
22	70	116 III	175	267	415 IV	605	915	1300	1950	2900

ZONE I : 10 to 48 ft./min. for ordinary tungsten tool (12 to 18% W) and thread cutting.
ZONE II : 50 to 100 ft./min. for cobalt-tungsten high speed tools (18% W + 5% Co).
ZONE III : 105 to 180 ft./min. for supra high-speed tools (15% Co + 1 to 2 Va + 18 to 20% W) and ordinary cemented carbides.
ZONE IV : 180 to 450 ft./min. for high grade cemented carbide, which could be used up to 3 000 ft./min. Cutting speed : Feet/min. ($V = \pi d n$).

Fig. 3.

by connecting the D.C. main motor running at 470 r.p.m. directly with the line shaft on ball bearings. The speed of the countershaft was increased at the same time to 350 r.p.m., which could just be taken without changing the self-lubricating bearings. Motor+main line+counter-shaft (idle) required, without the lathe, 0.7 kW. The idle running machine required 1.2 kW up to 1.8 kW, depending on the different numbers of revolutions. The cast-iron gears of the medium and low transmission, r_1, r_2, R_1, R_2, were kept as they were. The cast-iron gear r_3, however, was replaced by a new one of dense and resistant cast-iron. These gears were now strong enough to take cuts of 0.4 in. deep and 0.080 in. feed on cast-iron, corresponding to a chip area of 0.032 sq. ins. on a workpiece of 12 in. diameter. The main cutting force was 2,300 lb., the cutting speed 100 ft. per minute and the power equation $N = \frac{F.v}{21,000}$ was $\frac{2,300 \times 100}{21,000} = 10.8$ h.p. The ammeter showed 36 amp. with 230 volt D.C.=8.3 kW. Steel of 36 tons per sq. in. was turned with 400 ft. per minute, depth 0.2 in., feed 0.015 in., corresponding again to $\frac{600 \times 400}{21,000} = 11.4$ h.p.

The table Fig. 3 gives the speeds in feet per minute co-ordinated to the diameters from $\frac{1}{2}$ in. to 22 in. At the top the nine different existing numbers of revolutions from 20 to 500 are inscribed. The table should be used both by the rate-fixer and the operator of the lathe. The operator reads from the drawing the diameter of the piece to be turned, and gets from the piece ticket the speed and the kind of tool which the rate-fixer used to determine the time in minutes for the job.

The chart has four zones :—

ZONE I from 11 to 48 ft. per minute is for ordinary tungsten tools ranging from 20 to 48 ft. per minute, and for threading tools from 10 to 36 ft. per minute.

ZONE II from 50 to 100 ft. per minute is for cobalt-tungsten high-speed tools (5% Co., 18% W.).

ZONE III from 105 to 180 ft. per minute for super-high speed tools (15% Co., 18 to 20% W., 1 to 2 Va, and for best Stellite).

ZONE IV from 175 to 450 ft. per minute for best grade cemented tungsten carbides.

The power and the design of the rebuilt lathe did not allow 450 to 500 ft. per minute to be exceeded, whereas good cemented carbide-tipped tools allow the speed to be increased considerably more on hard steel but on a very rigid machine. Very important was the improvement of lubrication of the main bearings and the back gear sleeve. The small oilers were replaced by big sight-feed lubricators. The Acheson Oildag with colloidal graphite was used as lubricant,

the excellent efficiency of which kept the bearings cool whilst the speed was being raised to twice its original value. For the rotating sleeve of the rear shaft, however, it would be advisable to introduce a central lubrication using long bores in the axis and cross connections by which the grease could be pressed by a Stauffer lubricator.

When the machine ran the first time at 500 revolutions the oscillation of the whole fast headstock was unbearable. It moved more than ¼ in. sideways. The cause was the cone pulley, which was found to be partly rough internally. It was dismantled and carefully machined all over. Then the legs of the lathe were rigidly bolted to the foundation. To-day the machine is working at the maximum speed of 500 r.p.m. as smoothly as a modern machine, and is very useful for super-rapid tools, stellite and cemented carbides, which are better suitable for rough hard and not uniform cast-iron.

If the belt is not overloaded so that the main spindle never comes to a standstill, the cemented carbide tip is not endangered. The moment, however, that the spindle stops under full load, because the belt fails, the tip is cracked. (Fig. 4.)

Fig. 4.

Cemented carbides could be used with good advantage for the big diameters, i.e., large speeds, and with small chip areas which do not exceed the power of 12 h.p. For roughing purposes, the chip relations of depth to feed ought to be between 10 to 1 and 5 to 1. It is essential that the tools are clamped rigidly in the tool post; therefore the American tool post was replaced by two solid strips fastened with two 1 in. diameter bolts.

The cost of rebuilding the machine (new gears, balanced cone pulley, tool post, improved lubrication and foundation) amounted to about £50 and was done in six weeks altogether, whereas a new lathe of this size, 22 in. swing, 5 ft. between centres, 8 and 10 h.p., 3.6 tons weight, to-day requires a time of delivery of 40 weeks and costs at least £1,100.

1*st October*, 1940.